§9. Feasibility of Helium Gas Turbine System for Molten Salt Blanket

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1. Introduction

Gas turbines for nuclear energy use must be closed cycle and its maximum inlet temperature is restricted. Therefore, an improvement of thermal efficiency cannot be realized by any extension of conventional Blayton cycle and adoption of multi-stage compression/expansion process is a quite natural choice for cycle improvement.

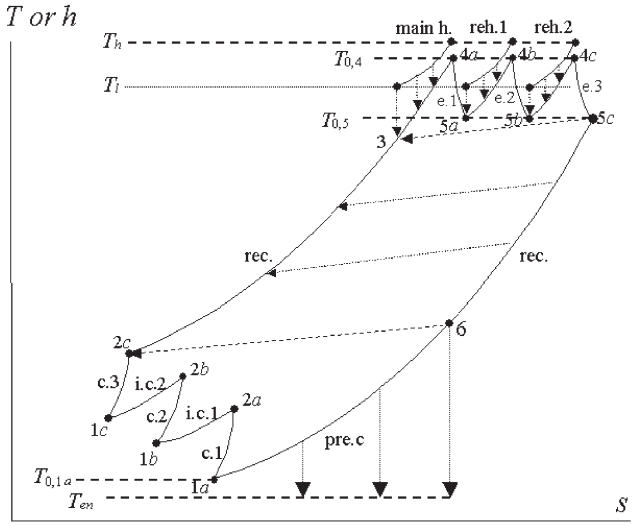

Fig. 1 Ts diagram for 3 stage-compression/expansion

3. Calculation of thermal efficiency

Following this, numerical estimation was performed on the thermal efficiency of multi-stage closed gas turbine cycle, the typical example of which is illustrated is Figs. 1. In the calculation, compression/expansion ratio was assumed to be common over all stages and optimized to give the maximum efficiency. Relative pressure loss was assumed to be,

$$\sum\left(\frac{\Delta p_0}{p_0}\right)=(\text{Number of heat exchanger path})\times 0.02\,,$$

while cycle maximum temp. $T_{0,4}$ was varied as 823～1273 [K] (550～1000 [℃]), every 50[K]. Environmental temp. was fixed at $T_{0,1}$=300[K]. Inter cooler heat exchange efficiency,

$$\varepsilon_{ic}=\frac{T_{0,2a}-T_{0,1b}}{T_{0,2a}-T_{0,1a}}=\frac{T_{0,2b}-T_{0,1c}}{T_{0,2b}-T_{0,1a}}=\cdots=\frac{T_{0,2(x-1)}-T_{0,1x}}{T_{0,2(x-1)}-T_{0,1a}}\,,$$

was assumed to be 0.9.

As Fig. 2 suggests, the perfect inter cooling with infinite numbers of infinitesimal cooling/compression stages is equivalent to approaching to isothermal heat rejection process of the Carnot cycle, while removal of the inter cooling corresponds to the adiabatic compression process of the Carnot cycle.

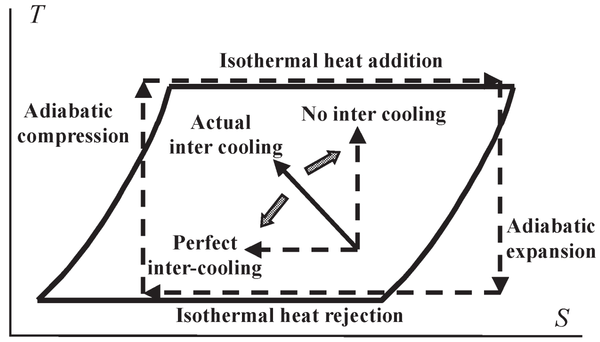

Fig.2 Carnot and Erricson: meaning of inter cooling level

Regenerative heat exchanger efficiency, $\varepsilon_{hx}=\left(T_{0,3}-T_{0,2c}\right)/\left(T_{0,5}-T_{0,2c}\right)$, was assumed to be 0.9 and polytropic efficiency was fixed at 0.9.

Table 1 Numerical results

	m	n	H.Ex. path	Pres. loss	$T_{0,4}$	ε_{hx}	ε_{ic}	$r_{c,best}$	$r_{e,best}$	η_{th}
①	1	1	2	0.04	823	0	-	3.78	0.276	0.227
②	1	1	4	0.08	823	0.9	-	2.00	0.541	0.288
③	2	1	5	0.10	823	0.9	0.9	1.55	0.463	0.308
④	1	2	5	0.10	823	0.9	-	2.29	0.696	0.295
⑤	2	1	5	0.10	823	0.9	1.0	1.57	0.451	0.313
⑥	3	1	6	0.12	823	0.9	0.9	1.39	0.423	0.310
⑦	3	1	6	0.12	823	0.9	1.0	1.41	0.405	0.316
⑧	1	3	6	0.12	823	0.9	-	2.49	0.769	0.289
⑨	2	2	6	0.12	823	0.9	0.9	1.72	0.619	0.328
⑩	2	3	7	0.14	823	0.9	0.9	1.84	0.699	0.331
⑪	3	2	7	0.14	823	0.9	0.9	1.53	0.568	0.339
⑫	3	3	8	0.16	823	0.9	0.9	1.62	0.652	0.347
⑬	3	4	9	0.18	823	0.9	0.9	1.70	0.703	0.348
⑭	4	3	9	0.18	823	0.9	0.9	1.51	0.614	0.355
⑮	4	4	10	0.20	823	0.9	0.9	1.57	0.674	0.358
⑯	4	5	11	0.22	823	0.9	0.9	1.62	0.711	0.358
⑰	5	5	12	0.24	823	0.9	0.9	1.53	0.687	0.366
⑱	5	5	12	0.24	823	0.9	1.0	1.57	0.669	0.376
⑲	5	5	10	0.20	823	0	1.0	2.13	0.489	0.291
⑳	3	3	6	0.12	823	0	1.0	2.42	0.430	0.263

4. Numerical results and summary

Table 1 summarizes the numerical results of thermal efficiency in which heat receiving temperature was fixed at corresponding liquid blanket allowable maximum temperature 823K (550℃). Indices (m,n) indicate the number of compression and expansion stages. Beginning with the simple Blayton cycle case ①, the thermal efficiency of various conditions were calculated.

As the table indicates, adoption of regenerative heat exchanger and perfect inter-cooling as well as increasing the number of compression/expansion stages means the departure from the Blayton cycle and entering the Erricson cycle which is ideally equivalent to the Carnot cycle. The only way of decreasing the pressure loss, the perfect inter cooling being retained, is to adopt the heating/cooling of the operating gas from the casing walls or within the flow paths between stator blades in both compressors and expanders, namely to adopt the isothermal expansion/heating and isothermal compression/cooling, which approaches the cycle shape form Blayton to Ericsson.